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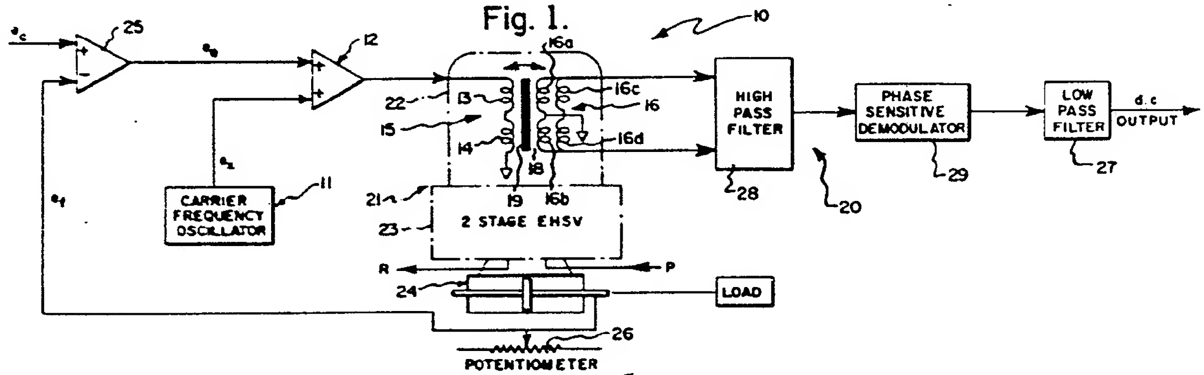
(54) Armature position detector

(57) Apparatus is provided for sensing the actual position of an armature in an electromagnetic driver 15, such as a torque motor, a solenoid, or the like. An oscillator 11 generates a relatively high frequency carrier signal e_x, which is superimposed on a relatively low frequency command signal e_c supplied to a drive coil 13, 14. Detector coils 16a—16d are positioned in a magnetic circuit, and are arranged to have induced therein, signals identical in frequency to the superimposed signals. The amplitude of the induced signals varies with armature position. The high frequency induced signal is separated 28 and demodulated 29 to provide an output signal indicating the actual position of the armature.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

Fig. 1.



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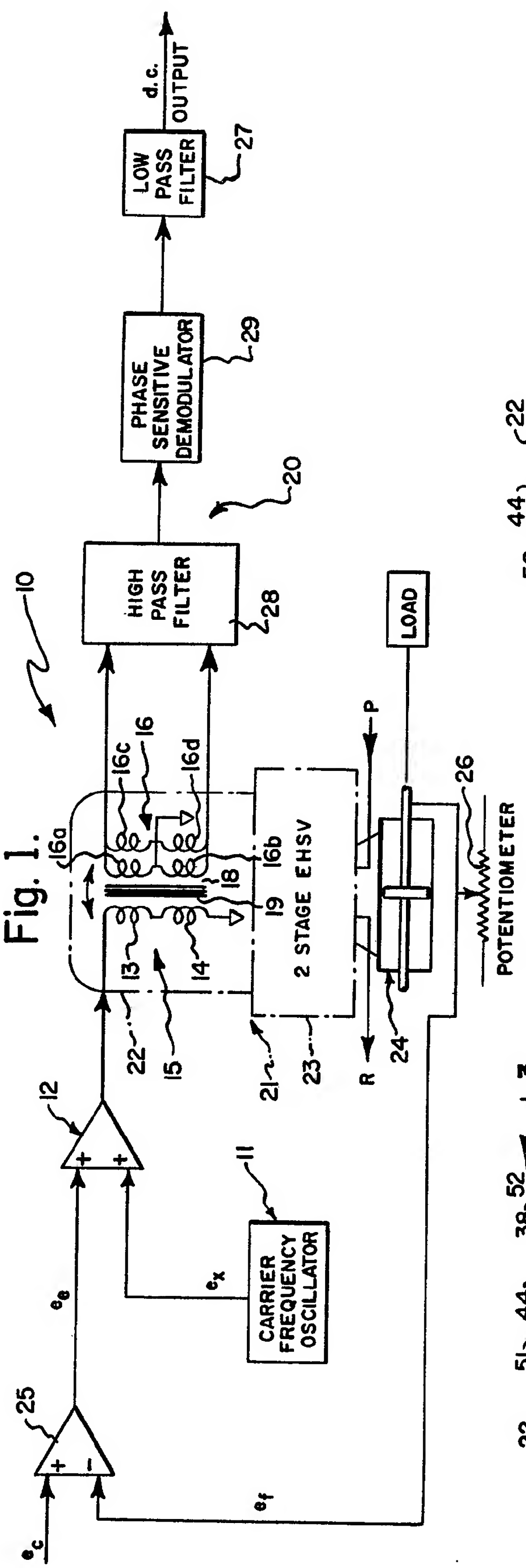

Fig. 1.

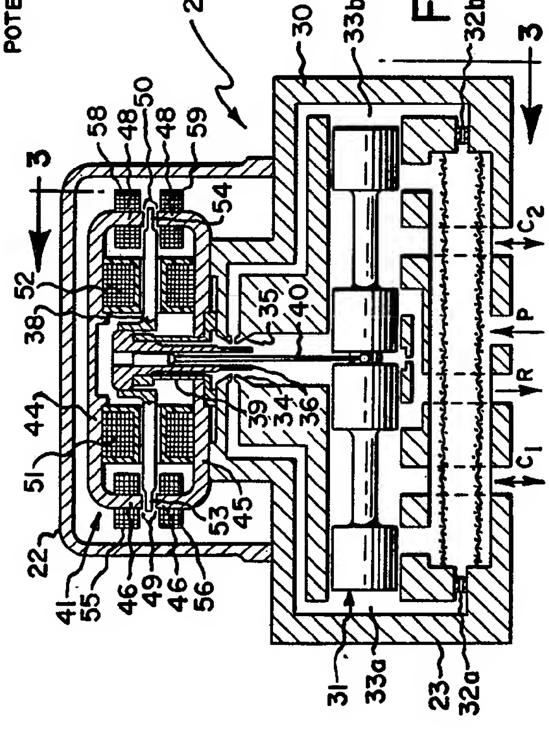

Fig. 2.

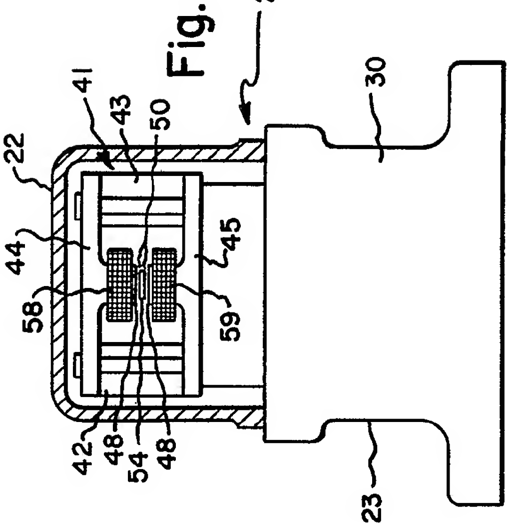

Fig. 3.

Fig. 4.

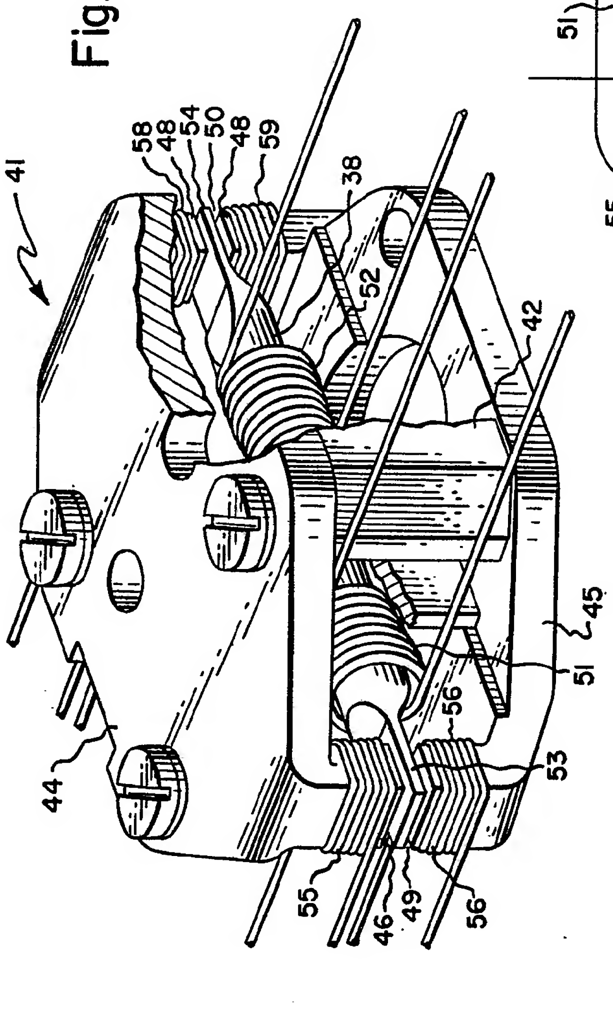
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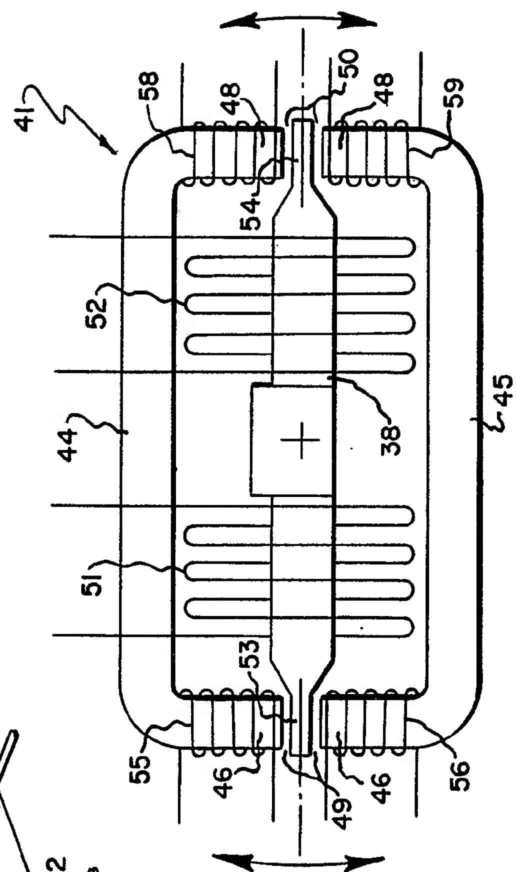
Fig. 5.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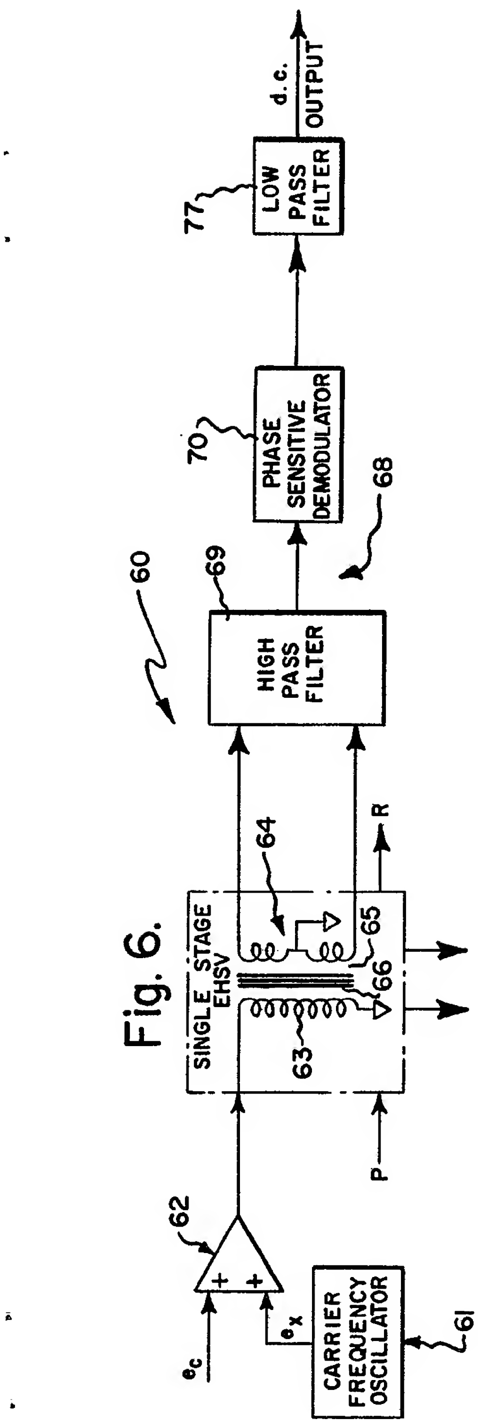

Fig. 6.

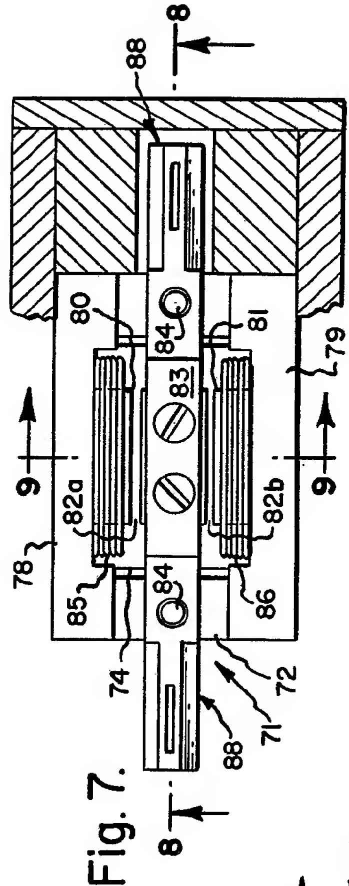

Fig. 7.

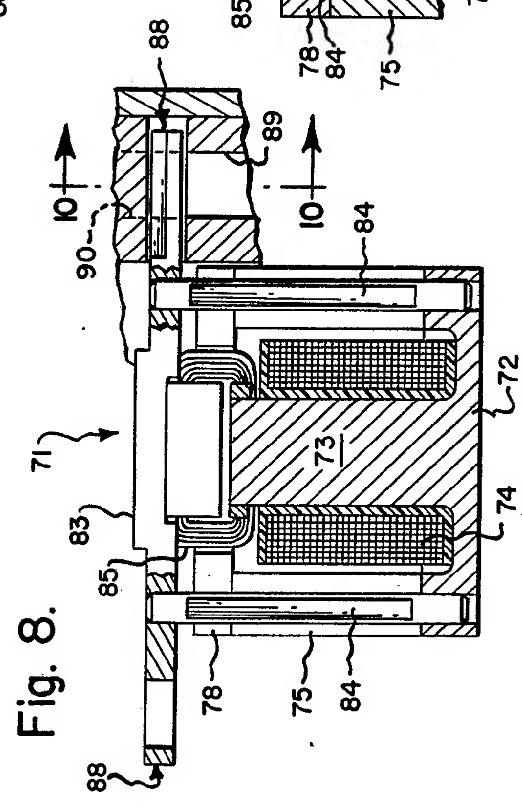

Fig. 8.

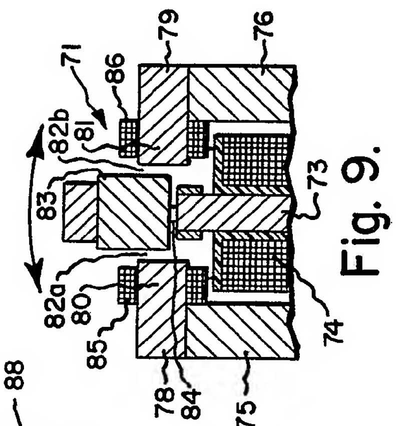

Fig. 9.

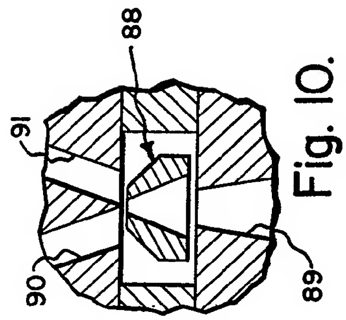

Fig. 10.

Fig. 12.

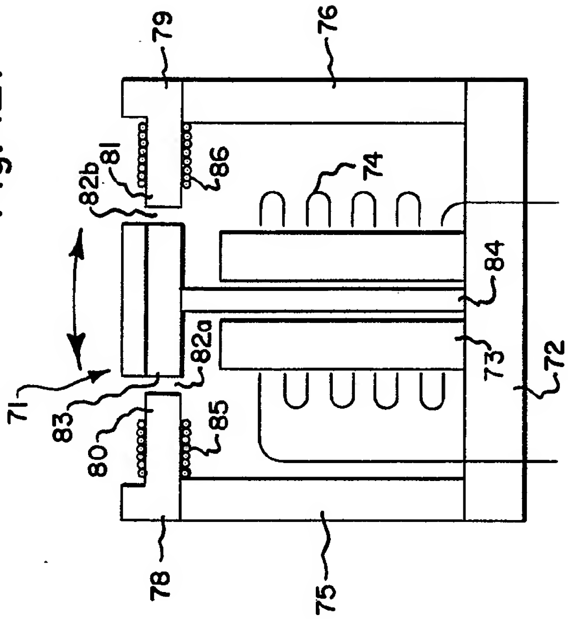
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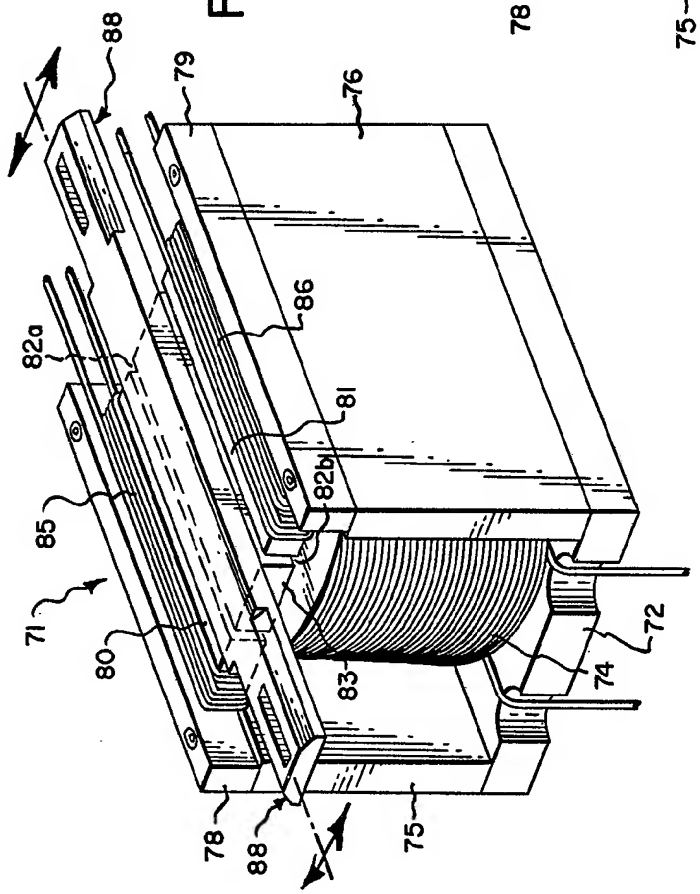
Fig. 11.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SPECIFICATION
Armature position detector

The present invention relates generally to the field of electromagnetic drivers, such as torque motors, solenoids and the like, and more particularly to improved apparatus for sensing the actual position of an armature in such an electromagnetic driver.

According to a first aspect of the invention, there is provided an electromagnetic driver comprising a drive coil arranged to be supplied with a relatively low frequency drive signal and adapted to produce a magnetic field in response to said drive signal, an air gap, an armature having a portion arranged in said air gap and adapted to be moved by said magnetic field, sensing means for sensing the position of said armature, said sensing means including an oscillator for generating a relatively high frequency carrier signal, summing means for superimposing said carrier and drive signals and for supplying such superimposed signals to said drive coil, detecting means arranged to sense the flux in said air gap and operative to have induced therein signals similar in frequency to said drive and carrier signals but having amplitudes reflective of the position of said armature, and separation means operatively arranged to separate such high frequency induced signal from such low frequency induced signal, whereby the amplitude of such separated high frequency induced signals may reflect the position of said armature.

According to a second aspect of the invention, there is provided an electromagnetic driver comprising a drive coil for producing an electromagnetic field on receipt of an alternating current drive signal, an armature for movement by the electromagnetic field to a position determined by the drive signal, an oscillator for generating an alternating current carrier signal, the carrier signal, in use, being combined with the drive signal before the application of both signals to the drive coil, the frequency of the carrier signal being such that the electromagnetic field produced thereby in the drive coil does not, in use, cause movement of the armature, a detector so arranged relatively to the drive coil and the armature that, in use the detector senses the electromagnetic field produced by the drive coil in response to the drive signal and the carrier signal and produces detected drive and carrier signals corresponding or substantially corresponding to the drive and carrier signals in frequency but having amplitudes which correspond to the position of the armature, and a separater for separating the detected drive signal from the detected carrier signal and for producing from the detected carrier signal a signal corresponding to the position of the armature.

The following is a more detailed description of one embodiment of the invention, by way of example, reference being made to the accompanying drawings, in which:—

Fig. 1 is a block diagram showing the improved sensing means in association with a two-stage electrohydraulic servovalve having a two-sided torque motor;

Fig. 2 is a vertical sectional view of the servovalve shown in Fig. 1, this view particularly showing the position of the detector coils proximate the air gaps;

Fig. 3 is a transverse vertical sectional view of the servovalve, taken generally on line 3—3 of Fig. 2;

Fig. 4 is a perspective view of the two-sided torque motor, with portions thereof broken away to more clearly illustrate the armature;

Fig. 5 is a schematic view of the two-sided torque motor;

Fig. 6 is a block diagram showing the improved sensing means in association with a single-stage electrohydraulic servovalve having a one-sided torque motor;

Fig. 7 is a top plan view of the torque motor indicated in Fig. 6;

Fig. 8 is a longitudinal vertical sectional view of the torque motor, taken generally on line 8—8 of Fig. 7;

Fig. 9 is a transverse vertical sectional view of the torque motor, taken generally on line 9—9 of Fig. 7;

Fig. 10 is a transverse vertical sectional view of the single stage servovalve, taken generally on line 10—10 of Fig. 8, and principally showing the flow deflector;

Fig. 11 is a perspective view of the one-sided torque motor, and

Fig. 12 is a schematic view of the one-sided torque motor.

At the outset, it should be clearly understood that like reference numerals are intended to identify the same elements and/or structure consistently throughout the several drawing figures, as such elements and/or structure may be further described or explained by the entire written specification, of which this detailed description is an integral part.

Referring now to the several drawing figures, and more particularly to Fig. 1 thereof, the sensing means, generally indicated at 10, is for sensing the actual position of an armature in an electromagnetic driver. As used herein, the term "electromagnetic driver" is broadly intended to mean a mechanism in which an armature is moved in response to a magnetic field. Many different species of torque motors, solenoids, and the like, fall within the generic meaning of the term "electromagnetic driver." Such electromagnetic drivers are commonly used as prime movers to generate a force or torque, which is used for some purpose. Specific examples of such uses of torque motors and propellant control valves, are representatively shown and described in U.S. Pat. Nos. 2,625,136, 2,767,689, 3,023,782, 3,455,330, 3,542,051, 3,373,769, and 3,884,267.

In Fig. 1, the improved sensing means 10 is shown as broadly including: an oscillator 11 operatively arranged to generate a relatively high frequency carrier signal; summing means 12

operatively arranged to superimpose the carrier signal e_x upon a relatively low frequency drive signal e_e, and to supply such superimposed signals to the drive coils 13, 14 of an electromagnetic driver 15; detecting means 16 operatively arranged to sense the flux in an air gap 18, and operative to have induced therein signals similar in frequency to the carrier and drive signals but having amplitudes reflecting the actual position of an armature 19 interposed in the air gap between the drive coils and the detecting means; and separation means 20 operatively arranged to separate such high frequency induced carrier signal from such low frequency induced drive signal. The separated high frequency induced signal may be used to indicate the actual position of the armature relative to the detecting means.

The electromagnetic driver shown in Fig. 1 is a torque motor of a two-stage "nozzle and flapper"-type electrohydraulic servovalve, generally indicated at 21, which has an electrical section 22 and a hydraulic section 23. This type of servovalve is more fully shown and described in the aforesaid U.S. Pat. No. 3,023,782. The output of the servovalve hydraulic section is supplied to a piston-and-cylinder actuator 24, which in turn is used to move a load.

More particularly, a relatively low frequency d.c. command signal e_c is supplied to an amplifier 25, which also receives a negative feedback signal e_f from a position transducer such as potentiometer 26, connected to the rod of the hydraulic actuator. The command input signal e_c indicates the desired position of the actuator rod, and the negative feedback signal e_f indicates its actual position. Amplifier 25 supplies the difference between the command and feedback signals, as an error or drive signal e_e to the summing means 12, which may be a summing amplifier. The relatively high frequency a.c. carrier signal generated by oscillator 11 is also supplied to summing amplifier 12, which superimposes the error and carrier signals and supplies such superimposed signals to the series-connected drive coils 13, 14 of the torque motor. The command signal e_c is a variable d.c. signal, and typically has a relatively low frequency on the order of 0—200 Hz. The oscillator 11 generates a relatively high frequency a.c. signal, typically on the order of a decade or more higher than the frequency of the command signal. Hence, if the frequency of the command signal is of the order of 0—200 Hz, then the carrier signal frequency may typically be from 2K Hz to 20K Hz. Because the carrier frequency exceeds the valve's frequency response capability, the servovalve will not respond to the signal generated by oscillator 11.

The detecting means 16 are shown as including four coils 16a, 16b, 16c and 16d, arranged in two separate series-bucking pairs. Hence, detector coils 16a and 16b form a first co-operative pair, and detector coils 16c and 16d form a second co-operative pair. The coils of each co-operative pair are arranged proximate the air gap 18 to sense the position of the armature. The superimposed error and carrier signals supplied to the torque motor's drive coils 13, 14, will induce signals of similar frequency in the detector coils. However, the position of armature 19 will modify the amplitude of such induced signals.

The separation means 20 is shown as including a high pass filter 28, a phase sensitive demodulator 29, and low pass filter 27. The signals induced in the detector coils are supplied to filter 28, which screens out the relatively low frequency induced drive signal, but allows the relatively high frequency induced signal to pass. The induced high frequency signal is then supplied to phase sensitive demodulator and low pass filter, which in turn produces a d.c. output signal indicating armature position by magnitude and polarity. Inasmuch as the detector coils function similarly to the secondary coils of a linear variable differential transformer (LVDT), the d.c. output signal supplied by the phase sensitive demodulator will vary linearly with armature position.

Hence, in the sensing means 10, a carrier signal, having a relatively high frequency exceeding the dynamic response capability of the electromagnetic driver, is superimposed on the lower frequency normal drive signal supplied to the drive coils. The drive signal produces a flux in the air gap which causes the armature to move relative to the fixed torque motor structure. Combined signals, identical in frequency to the superimposed signals, are induced in the detector coils. The amplitude of the induced signals reflects the armature position within the air gap. The high frequency induced signal is separated from the low frequency induced signal, and then converted into a d.c. output, which varies essentially proportional to armature position. Thus, the magnitude and polarity of the d.c. output signal indicates the actual position of the armature. One unique aspect of the improved sensing means is that it is possible to continually monitor the actual position of the armature as the armature moves in response to the drive signal during normal operation of the driver.

The physical structure of the servovalve schematically illustrated in Fig. 1, is more fully shown in Figs. 2—5. Inasmuch as this servovalve is more fully described in the aforesaid U.S. Pat. No. 3,023,782, save for the provision of the detector coils, the ensuing description of same will be somewhat abbreviated.

Referring now to Figs. 2 and 3, servovalve 21 is shown as having a body 30 provided with a cylindrical chamber in which a four-lobed valve spool 31 is slidably mounted. The bottom of body 30 is provided with four ports: one being a pressure port P; another being a return port R; and the remaining two being a pair of co-operative control ports C_1 and C_2, which may be used to control the flow of fluid to hydraulic actuator 24. Hydraulic fluid supplied to the valve through pressure port P is applied through orifices 32a, 32b to left and right spool end chambers 33a, 33b, and is discharged through left and right

nozzles 34, 35 against opposite sides of a flapper 36. This flapper is a rigid tubular member and has an armature 38 mounted on its upper end. The hydraulic section of this valve is isolated from its electrical section by a flexure tube member 39, upon the upper end of which the armature-flapper member is mounted. A spring wire 40 provides mechanical feedback between the valve spool and the armature-flapper member.

Referring now to Figs. 2—5, the torque motor, generally indicated at 41, is shown as including a pair of front and rear horizontally-spaced permanent magnets 42, 43 (Fig. 3) operatively interposed between a pair of vertically-spaced upper and lower pole plates 44, 45. The corresponding ends of the pole plates are bent toward one another to form spaced and opposing polepieces, those on the left side being severally indicated at 46 and those on the right side being severally indicated at 48. These left and right polepieces 46, 46 and 38, 38 define left and right air gaps 49 and 50, respectively, therebetween. Left and right drive coils 51, 52 surround the armature 38 and are arranged between the pole plates on the opposite sides of the flapper. As schematically indicated in Fig. 1, these two drive coils may be arranged in series with one another. The armature 38 is shown as having left and right marginal plate portions 53, 54 arranged in left and right air gaps 49, 50 respectively. Hence, a suitable electrical drive signal may be supplied to the drive coils to create a magnetic field in the air gaps, thereby to selectively cause the armature to move in either a clockwise or counter-clockwise direction. Such pivotal movement of the armature causes the flapper to move close to one nozzle and farther away from the other, thereby producing a pressure differential in the valve spool end chambers and shifting the valve spool in the appropriate direction to establish flow through valve control ports C_1 and C_2. A more complete description of the structure and operation of this servovalve may be found in the aforesaid U.S. Pat. No. 3,023,782.

The torque motor 41 shown in Figs. 2—5 has been modified slightly from that shown in U.S. Pat. No. 3,023,782 to allow for the provision of four detector coils 55, 56, 58 and 59, which are arranged about the polepieces proximate the air gaps. Specifically, a first co-operative pair of detector coils 55, 56 encircle the left polepieces, respectively, so as to be arranged to sense the flux in the left air gaps 49. Similarly, the second co-operative pair of coils 58, 59 encircle the upper and lower right polepieces, so as to be arranged to sense the flux in the right air gaps 50. The coils of each co-operative pair are arranged to be series-bucking so that as the associated armature plate portion moves closer to one polepiece, the signal induced in the proximate coil will be favored at the expense of its co-operative mate. Thus, each co-operative pair of detector coils functions in a manner akin to the secondary coils of a linear variable differential transformer. It should also be noted that if the armature were mounted for movement about a perfect "dead center" axis, its plate portions 53, 54 would be ideally spaced equally from diametrically opposite polepieces. However, the pivotal movement of the armature is accommodated by flexure or bending of flexure tube member 39. Hence, the effective axis for such armature pivotal movement does not coincide with an ideal "dead center" location. By using two co-operative pairs of detector coils, the position of the armature left and right plate portions relative to the associated polepieces, can be determined. However, while it is presently preferred to use two co-operative pairs of detector coils in the torque motor shown in Fig. 1, one of these pairs might be omitted, if desired.

Use of the improved sensing means in association with a "jet and jet deflector"-type of servovalve, is shown in Figs. 6—12. This servovalve is regarded as being a "single-stage" type because there is just one hydraulic amplifier (i.e., the jet deflector) rather than two, as is provided by the nozzles/flapper and spool of the servovalve shown in Fig. 1. The "jet and jet deflector"-type of servovalve is more fully shown and described in the aforesaid U.S. Pat. No. 3,542,051. Whereas the improved sensing means was associated with a "two-sided torque motor" in Figs. 1—5, a "one-sided torque motor" is illustrated in the valve shown in Figs. 6—12.

Referring now to Fig. 6, a second preferred embodiment of the improved sensing means, generally indicated at 60, is shown as again including: an oscillator 61 for generating a relatively high frequency carrier signal; summing means 62 arranged to superimpose the carrier signal e_x on a valve command or drive signal e_c and to supply such superimposed signals to the torque motor drive coil 63; detecting means, generally indicated at 64, arranged to sense the flux in air gap 65 and operative to have induced therein, signals similar in frequency to the superimposed drive and carrier signals, but having amplitudes reflective of the position of an armature 66. The signals induced in the detector means are again supplied to separation means 68, which includes a high pass filter 69, a phase sensitive demodulator 70, and a low pass filter 77. As with the first embodiment, the output of the phase sensitive demodulator and low pass filter is a d.c. signal, the magnitude and polarity of which indicate the actual position of the armature with respect to the detecting means.

The "one-sided torque motor" is generally indicated at 71 in Figs. 7—12. Torque motor 71 includes a base 72 provided with a central core 73 upstanding therefrom, a drive coil 74 wrapped around the core, left and right permanent magnets 75, 76 mounted on the base, left and right pole plates 78, 79 mounted on the magnets and having their inwardly-facing end faces arranged to form spaced and facing left and right polepieces 80, 81. The spacing between polepieces 80, 81 and armature 83 constitutes air gaps 82a, 82b. The armature 83 is supported in this position by two flexure tube members 84, 84, which allow the

elongated armature to move back and forth toward the proximate polepiece (Fig. 9) in response to a magnetic field produced by drive coil 74. A co-operative pair of left and right detector coils 85, 86 are wrapped around the polepieces 80, 81, respectively. As best shown in Figs. 7 and 10, one or more ends of the armature may be provided with a deflector 88 which may move with the armature to deflect and proportionally divide a fluid jet supplied by a pressurized nozzle 89 between two receiver passages 90, 91 to establish the desired flow through the servovalve. As with the first embodiment, detector coils 85, 86 are arranged to be series-bucking, and function in a manner akin to the secondary coils of a linear variable differential transformer. While the signals induced in the detector coils will have a frequencies identical to the superimposed drive and carrier signals supplied to the drive coil, the amplitude and polarity of such induced signals reflect the position of the armature relative to the polepieces.

Persons skilled in this art will recognize that various changes and modifications may be made without departing from the scope of the invention as defined by the appended claims. For example, the improved sensing means may be associated with other types of torque motors, a wide variety of solenoids, and other electromagnetic actuators and drivers. Whether one or more co-operative pairs of series-bucking detector coils are used, is considered to be a matter of design choice depending upon the nature of armature motion, the symmetry and construction of the electromagnetic driver, and the desired level of induced signal. Similarly, the specific design and placement of such detector coils is regarded as falling within the ambit of one skilled in this art. In the improved sensing means, the drive coil performs two functions: first, to create a magnetic field sufficient to move the armature as desired, and, secondly, to induce signals in the detector coils. It is also deemed preferably that the frequency of the carrier signal be so in excess of the frequency response capability of the servovalve or the electromechanical driver, as to have a negligible, if any, effect on valve or driver response. While it is suggested that such carrier frequency be on the order of ten or more times the maximum frequency of the command signal to the driver, the specific frequency relationship between the carrier and drive signals may be readily varied by one skilled in this art.

Therefore, while two preferred embodiments of the improved sensing means have been shown and described, and several modifications thereof discussed, persons skilled in this art will readily appreciate that various additional changes and modifications may be made without departing from the scope of the invention, which is defined by the following claims.

CLAIMS

1. An electromagnetic driver comprising a drive coil arranged to be supplied with a relatively low frequency drive signal and adapted to produce a magnetic field in response to said drive signal, an air gap, an armature having a portion arranged in said air gap and adapted to be moved by said magnetic field, sensing means for sensing the position of said armature, said sensing means including an oscillator for generating a relatively high frequency carrier signal, summing means for superimposing said carrier and drive signals and for supplying such superimposed signals to said drive coil, detecting means arranged to sense the flux in said air gap and operative to have induced therein signals similar in frequency to said drive and carrier signals but having amplitudes reflective of the position of said armature, and separation means operatively arranged to separate such high frequency induced signal from such low frequency induced signal, whereby the amplitude of such separated high frequency induced signal may reflect the position of said armature.

2. An electromagnetic driver according to claim 1 wherein said detecting means includes two detector coils.

3. An electromagnetic driver according to claim 2 wherein said detector coils are arranged to be series-bucking.

4. An electromagnetic driver according to any one of claims 1 to 3 wherein said summing means is a summing amplifier.

5. An electromagnetic driver according to any one of claims 1 to 4 wherein said separation means includes a high pass filter and a demodulator.

6. An electromagnetic driver according to claim 5 wherein said high pass filter is frequency sensitive, and said demodulator is phase sensitive.

7. An electromagnetic driver according to any one of claims 1 to 6 wherein said driver is a torque motor.

8. An electromagnetic driver comprising a drive coil for producing an electromagnetic field on receipt of an alternating current drive signal, an armature for movement by the electromagnetic field to a position determined by the drive signal, an oscillator for generating an alternating current carrier signal, the carrier signal, in use, being combined with the drive signal before the application of both signals to the drive coil, the frequency of the carrier signal being such that the electromagnetic field produced thereby in the drive coil does not, in use, cause movement of the armature, a detector so arranged relatively to the drive coil and the armature that, in use, the detector senses the electromagnetic field produced by the drive coil in response to the drive signal and the carrier signal and produces detected drive and carrier signals corresponding or substantially corresponding to the drive and carrier signals in frequency but having amplitudes which correspond to the position of the armature, and a separater for separating the detected drive signal from the detected carrier signal and for producing from the detected carrier signal a signal

corresponding to the position of the armature.

9. An electromagnetic driver substantially as hereinbefore described with reference to Figures 1 to 5 or to Figures 6 to 9 or to Figures 10 to 12 of the accompanying drawings.

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